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Progress Report No. 3

STABLE ISOTOPE ANALYSIS OF 1987 AND 1988 ZOOPLANKTON SAMPLES AND BOWHEAD WHALE TISSUES

By

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Principal Investigator

Reporting Period: 28 January 1990 - 31 May 1990

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I. TITLE

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III. SUMMARY

This report describes the progress to June 1990 on the stable isotope analysis of bowhead whale tissue samples and bowhead whale prey organisms collected by the PI and the North Slope Borough over the years 1987 and 1988. By virtue of two opportunities to sample zooplankton in U.S.S.R. waters off the Chukotka Peninsula and in the Gulf of Anadyr, we now have data from areas where bowheads feed on the return migration and part of their overwintering range. We also have collected additional samples from the U.S. side of the Chukchi Sea from the SURVEYOR in September - October 1989. The three years also offer an opportunity to investigate the effects of marked variation in physical environment--1987 and 1989 were very light ice years whereas 1988 was one of the heaviest ice years on record in the Chukchi and northern Bering seas. The Bering Sea did not become totally ice-free at any time in the summer of 1988.

Our findings support the initial conclusions (Saupe et al. 1989) that the zooplankton of the Bering and southern Chukchi seas are enriched in ^{13}C

relative to the eastern Beaufort Sea. We also confirmed that euphausiids are enriched in ^{13}C relative to copepods, first reported by Schell et al. (1987). On the ecosystem scale, the zooplankton sampled in 1987 are approximately one ‰ enriched relative to the same taxa sampled in 1988 and 1989. We do not have sufficient supporting information to allocate a source for this change but the pending analysis of the inorganic carbon pool may provide some insight into the mechanisms governing the change.

The analysis of bowhead whale baleen from animals taken in 1987 and 1988 continues to support the findings regarding both feeding and growth rates as described in Schell et al. (1989a,b). Bowheads are a slow growing whale (-0.4 m/yr) and the young animals between year one and about 6 - 7 years of age undergo a period of little or no linear growth. We now estimate that bowheads require 16 - 19 years to reach the assumed length of sexual maturity at 13 - 14 m.

IV. PURPOSE AND SCOPE

This project seeks to acquire information on the natural history and habitat requirements of bowhead whales in arctic Alaska. The technique employed uses the abundances of the stable isotopes of carbon as natural tracers of food intake from various environments in which the whales feed. The long baleen plates of bowhead whales serve as feeding records in that the stable isotopes are incorporated into the protein at the time of feeding and remain unchanged thereafter. Since the isotope abundances in the plates must be matched with prey from the differing geographic regions in which the animals feed, zooplankton samples were collected using ships of opportunity at locations throughout the Bering and Chukchi seas. Bowhead whale tissue samples were obtained from harvested whales in 1987 and 1988 through cooperation of the North Slope Borough. The analysis and interpretation of the stable isotope data from these samples constitutes the tasks of this project.

V. ISOTOPE RATIOS IN FOOD WEB STUDIES

Ecosystem studies involving biochemical systems usually depend upon two approaches. One approach is to construct budgets or mass balances of a key element and attempt to determine which fluxes dominate these budgets. The second-approach measures the key rates or processes within the system and then attempts to relate the findings to the overall goal. Although ideally the two approaches should be complementary and finally coalesce into a better understanding of the ecosystem, this goal is usually difficult to attain. There may be mismatches between time and space scales of the two approaches or processes which can not be determined to the required accuracy. Many of these quandaries are evident in any attempt at. estimating the feeding requirements of bowhead whales. Because stable isotope ratios can contribute both source (tracer) information and process information, they are ideally suited for the measurement of elemental movements--in this case carbon.

The field of stable isotope tracers has steadily expanded and a wealth of information on terrestrial and aquatic applications is now available. Fry and Sherr (1984) and Peterson and Fry (1987) review these applications and discuss the strengths and weaknesses of the many studies. Rundel et al. (1989) present a series of papers on various applications including several multiple isotope tracer studies.

The fidelity of consumers to the isotopic compositions of diet underlies all natural abundance studies. DeNiro and Epstein (1978) plotted diet vs. consumer isotope ratio and found that the transfer was conservative with regard to the whole animal. A small enrichment occurs of about one ‰ per trophic step, typically slightly larger with herbivores and less with carnivores. This has been documented in both field and laboratory studies (see review by Peterson and Fry 1987, McConnaughey and McRoy, 1979). Jones et al. (1981) documented the change in isotope ratios of cattle fed C-3 plants then changed to C-4 plants, then switched back again. Within 70 days, newly grown hair had reached equilibrium with the new diet after each change. Since the hair required several days to reach the surface of the skin prior to being shaved, actual response was faster than the isotope ratios in the shavings indicated.

Within organisms, the complex pathways of biosynthesis can alter the isotope ratios in the end products relative to starting materials. The distribution of carbon isotopes has been studied by several authors (Tieszen et al. 1983; DeNiro and Epstein 1978; Jones et al. 1981; Mizutani and Wada 1988). Muscle tissue tends to closely approximate diet whereas keratinous proteins--hair, feathers, and hooves--are typically enriched by

2-30/.. relative to diet. Schell et al. (1989b) found that keratin in baleen averaged about one ‰ heavier than muscle which in turn was about 6‰ heavier than lipids. Polar bears, which are 1 - 2 trophic levels above bowhead whales, also show an enrichment in keratin $\delta^{13}C$ of 1-2‰ relative to the whales. As more and more studies are performed on ecosystem processes, the usefulness of stable isotope ratios as tracers has become increasingly evident.

Natural history investigations of the large baleen whales present formidable problems due to the difficulties in observing the animals in their natural environments. Recently we have shown (Schell et al. 1989a, b) however, that bowhead whales (*Balaena mysticetus*) have marked annual oscillations in stable carbon and nitrogen isotope abundances along the length of the baleen plates in the mouth. These oscillations result from the annual migration of the animals from wintering grounds in the Bering Sea to the summering areas of the Canadian Beaufort Sea. Zooplankton along the migrational path have differing isotopic abundances of carbon and nitrogen which are reflected in the composition of the keratin in the continuously growing baleen plates. Since up to 20 years feeding record may be present in the plates of a large bowhead whale, considerable insight may be gained on the natural history of the whales and their habitat usage. Saupe et al. (1989) reported on the isotopic abundances in zooplankton prey which produce the large variations in *B. mysticetus*, and Schell et al. 1989b) presented a revised growth rate for *B. mysticetus*, determined through isotopic ageing techniques,

The isotope ratios in the baleen and especially in the muscle and visceral fat of animals killed in the spring compared to those killed in fall show that the greatest abundance of points along the traces from *B. mysticetus* correspond to isotopic abundances typical of prey species in the western and southern areas of the migratory range. The average ^{13}C isotopic abundance in visceral fat and muscle tissue from spring-killed *B. mysticetus* was enriched by 2.1 ‰ relative to two fall-killed animals implying that a major fraction of the total carbon of the animal was derived from the western and southern parts of their annual range. Although at this time it is impossible to accurately estimate the relative amounts of food that the whales obtain from the Beaufort versus Chukchi versus Bering seas, these data contrast with previous feeding scenarios which suggested that bowheads feed in the summer in the eastern Beaufort

Sea and relied almost entirely on stored reserves for the winter.

VI. PROGRESS-TO-DATE

The conclusions that we presented (Schell et al. 1987) based on past data were criticized by a review panel convened by the North Slope Borough. They felt there were too few data regarding (1) the zooplankton from around the range of the bowhead, and (2) the lack of data regarding the cause of the purported isotopic shift between the southwestern and northeastern segments of the migratory range. We recognized these shortcomings well before the review and sought to collect the necessary samples to fill the data gaps using ships of opportunity. This report presents the results of the stable isotope analysis of the samples collected over the following two years for which this study was conducted.

We are ten months into the project and completion of the analytical work is on schedule. The analyses consist of three phases: 1) initial sampling, weighing and preparation of the material for combustion to carbon dioxide; 2) cryogenic cleaning of the carbon dioxide following combustion; and 3) mass spectrometry and synthesis of the data. We are still sampling and processing the final large plates from the 1988 whales and are well under way with the mass spectrometry. A new mass spectrometer is now operational and this has facilitated a faster throughput of samples during the past few weeks. The mass spectrometer lab was shut down in April as the operator was at a conference in the Soviet Union and the Principal Investigator was on leave in Europe. Almost all of the zooplankton samples have been processed and the mass spectrometry completed. These samples are being compiled in a data base for statistical treatment and should be completed in the next few months.

Carbon dioxide samples from seawater have required that a new stripping system be constructed for removing the carbon dioxide and drying the samples. We have recently finished construction of this line and the sample processing is ready to begin.

Task Status as of 15 June 1990

Zooplankton Samples

THOMAS G. THOMPSON - July 1987

Sample preparation and weighing -- 100% completed

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

SURVEYOR Cruise - Sep-Ott 1987

Sample preparation and weighing -- 100% completed

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

ALPHA HELIX Cruise - May 1988

Sample preparation and weighing -- 1 00%

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

AKADEMIK KOROLEV Cruise - July - August 1988

Sample preparation and weighing -- 100%

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

THOMAS WASHINGTON Cruise. September - October 1988

Sample preparation and weighing -- 100%

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

SURVEYOR Cruise. October 1988

Sample preparation and weighing -- 100%

Combustion and cryogenic cleaning -- 100%

Mass spectrometry -- 100%

Bowhead Whale Baleen, Muscle and Fat Samples

1987 whales

Sample preparation and weighing -- 100% completed

Combustion and cryogenic cleaning -- 97%

Mass spectrometry -- 97%

1988 whales

Sample preparation and weighing -- 100%

Combustion and cryogenic cleaning -- 64%

Mass spectrometry -- 64%

Water Carbon Dioxide

1987 samples

Stripped and collected -- 0%

Mass spectrometry -- 0%

1988 samples

Stripped and collected -- 0%

Mass spectrometry -- 0%

VII. OBJECTIVES

Our overall goal is to use the isotopic gradients in the zooplankton of the Bering-Chukchi-Beaufort seas as natural tracers to determine the habitat dependencies and feeding strategies of the bowhead whale. The objectives of this study are listed as specific tasks below:

1. Complete isotopic analysis on the baleen and bowhead whale tissue samples collected over the 1987 and 1988 Inupiat whaling seasons.

2. Complete isotopic analysis on zooplankton collected from the Bering and Chukchi seas during 1987 and 1988. These samples were obtained by project personnel from the R/V ALPHA HELIX (June-July), R/V THOMPSON cruise for the ISHTAR program (August) and from the NOAA ship SURVEYOR

[September-October) in 1987. In 1988, samples were collected from the AKADEMIK KOROLEV in both U.S.S.R. and U. S. waters, the ALPHA HELIX in the Bering Sea, the THOMAS WASHINGTON in both U.S.S.R. and U.S. waters and from the SURVEYOR in the Chukchi and Bering seas in October. Sample locations and dates of collection are shown in Figures 1 - 7 The samples span the critical northern Bering - southern Chukchi region for which very little data were previously available and the U.S.S.R. waters of the Anadyr Gulf and off the Chukotka peninsula.

3. Collect and analyze samples of water column total carbon dioxide to establish the mechanisms causing the geographic shift in isotopic abundances. These samples were collected concurrently with the zooplankton sampling on the cruises noted above.

4. Interpret and synthesize new data in context with past findings to confirm or deny current interpretations of bowhead whale natural history with special reference to the role of the eastern Alaskan Beaufort Sea as feeding habitat. Data will be tested statistically to obtain seasonal and geographic patterns which may be applied toward estimating the food acquired by bowhead whales from the various habitats occupied over the seasonal migration. Details of the statistical treatments are described in Methods, below.

These samples provide a comprehensive assessment of bowhead whale prey over most of the range of the animals and comparative samples from adjacent waters such as the eastern half of the Bering Straits. Fortuitously, the sampling also occurred at the extremes of ice conditions. Year 1987 was one of the lightest ice years ever recorded and 1988 was the heaviest ice year recorded since satellite imagery has been available. This contrast may have affected primary productivity regimes over the summer season and contributed to differing isotope ratios in the resulting food chain. Semiquantitative zooplankton biomass data are being prepared from AKADEMIK KOROLEV,and THOMAS WASHINGTON samples. This information will be provided by the separately funded NSF - ISHTAR program personnel. The difficulties in sampling euphausiids will make net tow data unreliable with regard to estimating food availability to whales. Eventually we will need a MOCNESS sampler or equivalent to obtain better catches of euphausiids.

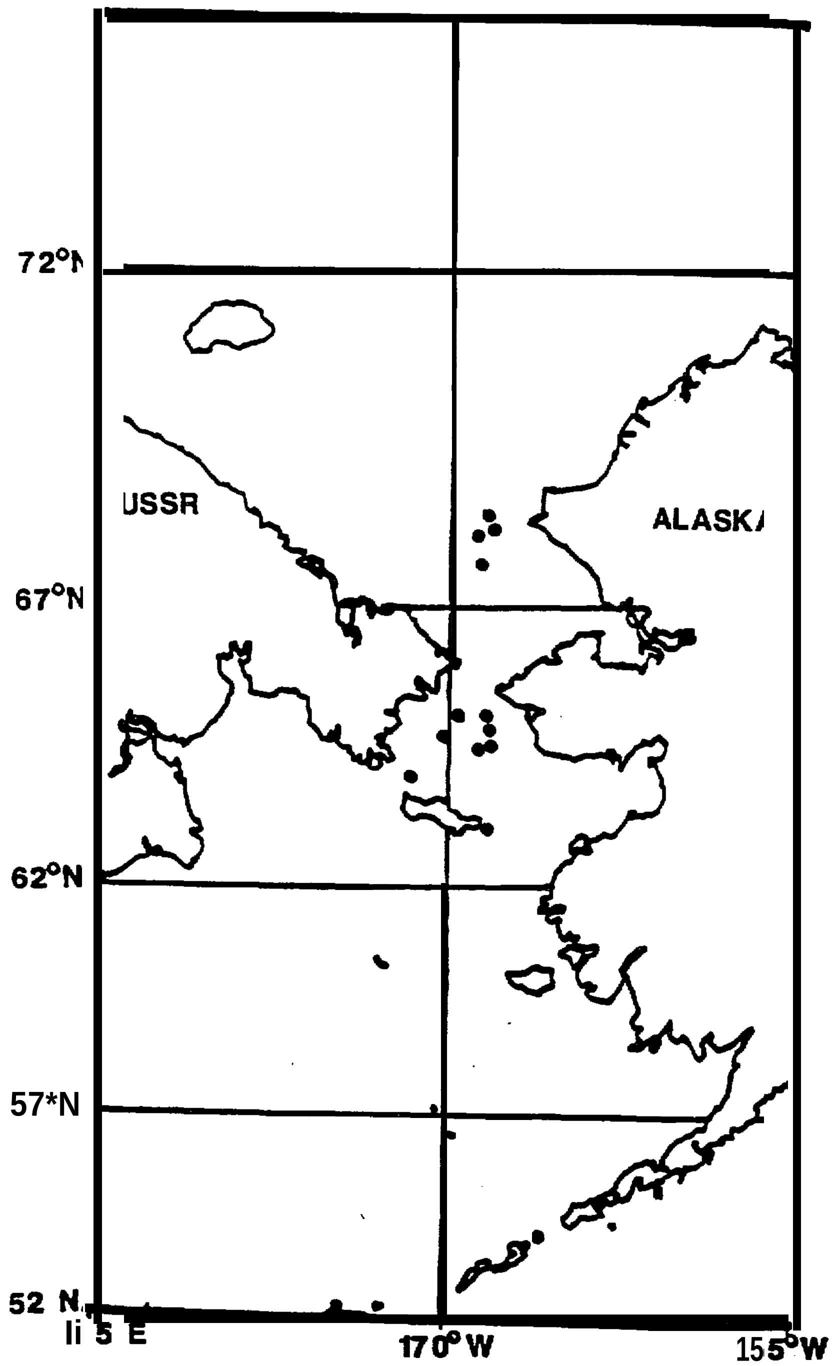

Figure 1. Stations sampled for zooplankton from the R/V THOMAS E. THOMPSON, August 1987 (TH87).

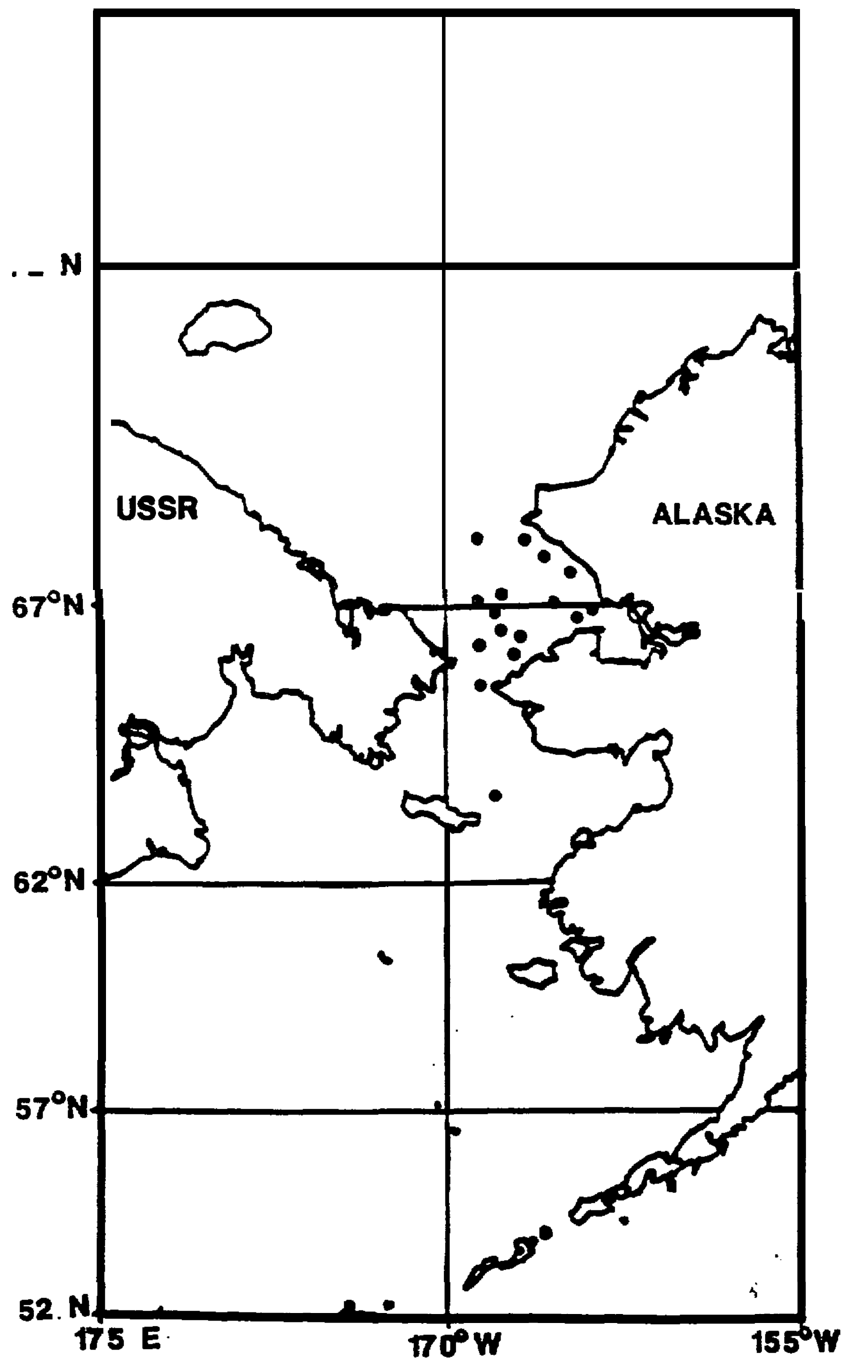

Figure 2. Stations sampled for zooplankton from the R/V SURVEYOR, September - October 1987 (SU87).

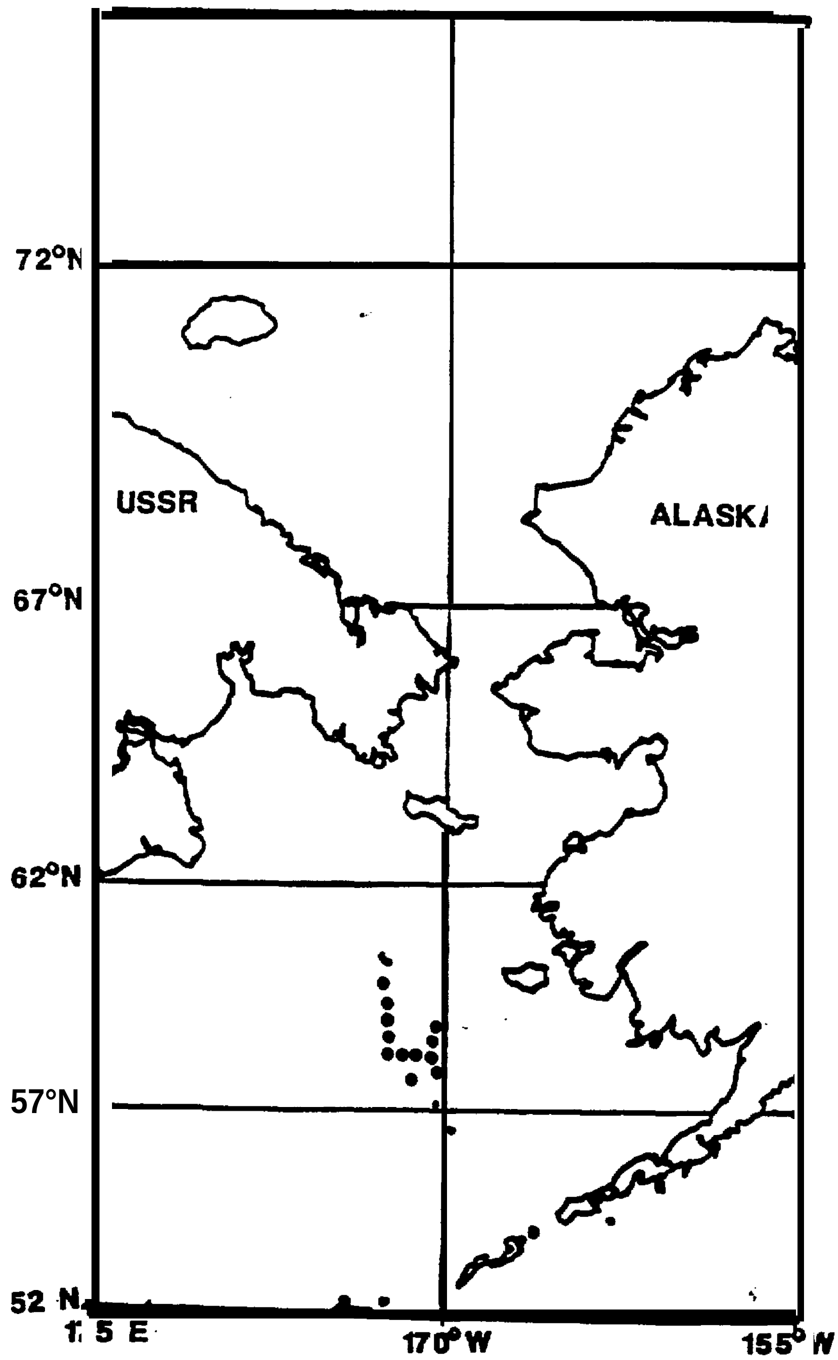

Figure 3. Stations sampled for zooplankton *from* the R/V ALPHA HELIX, Ice Edge Cruise, May 1988 (IE88).

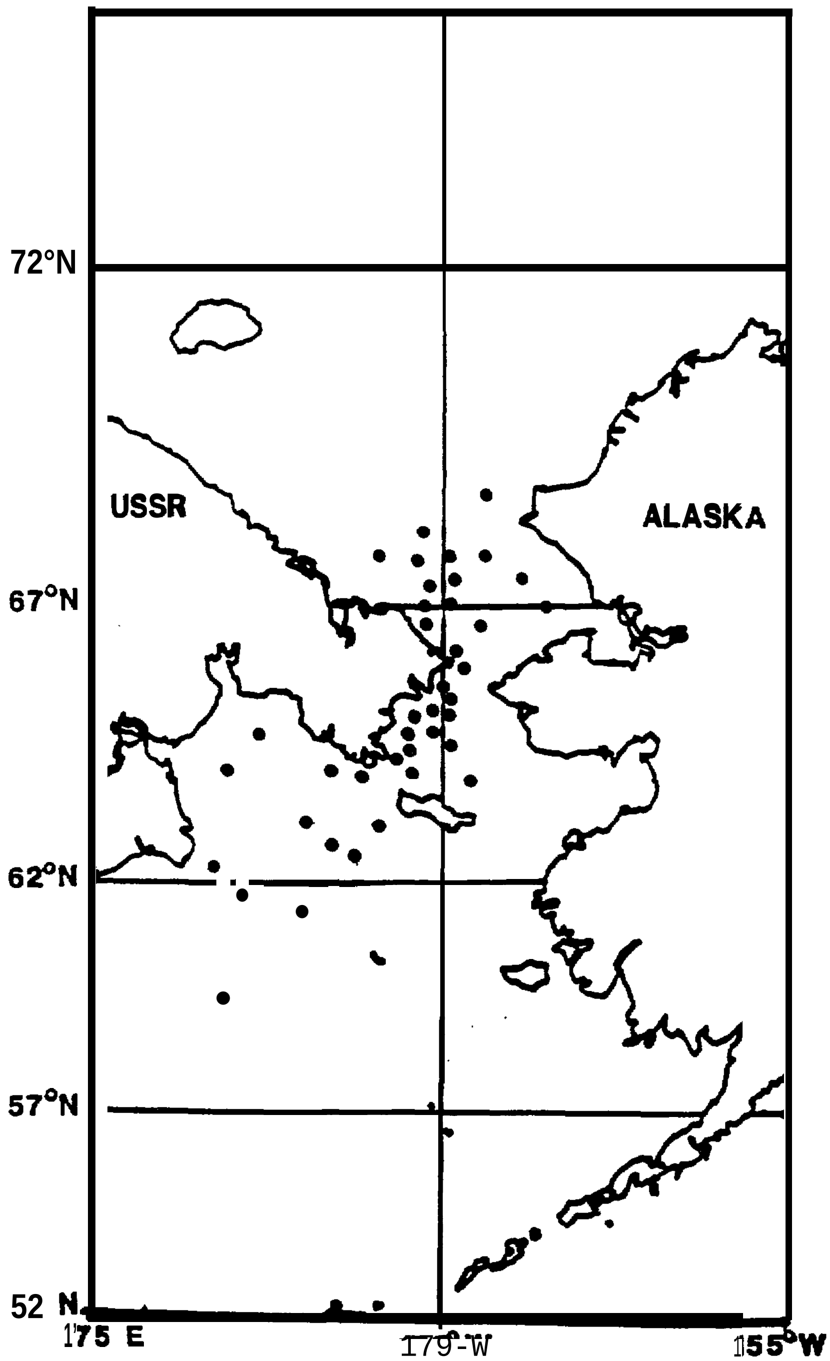

Figure 4. Stations sampled for zooplankton from the Soviet ship, R/V AKADEMIK KOROLEV, July-August, 19S8 (AK88).

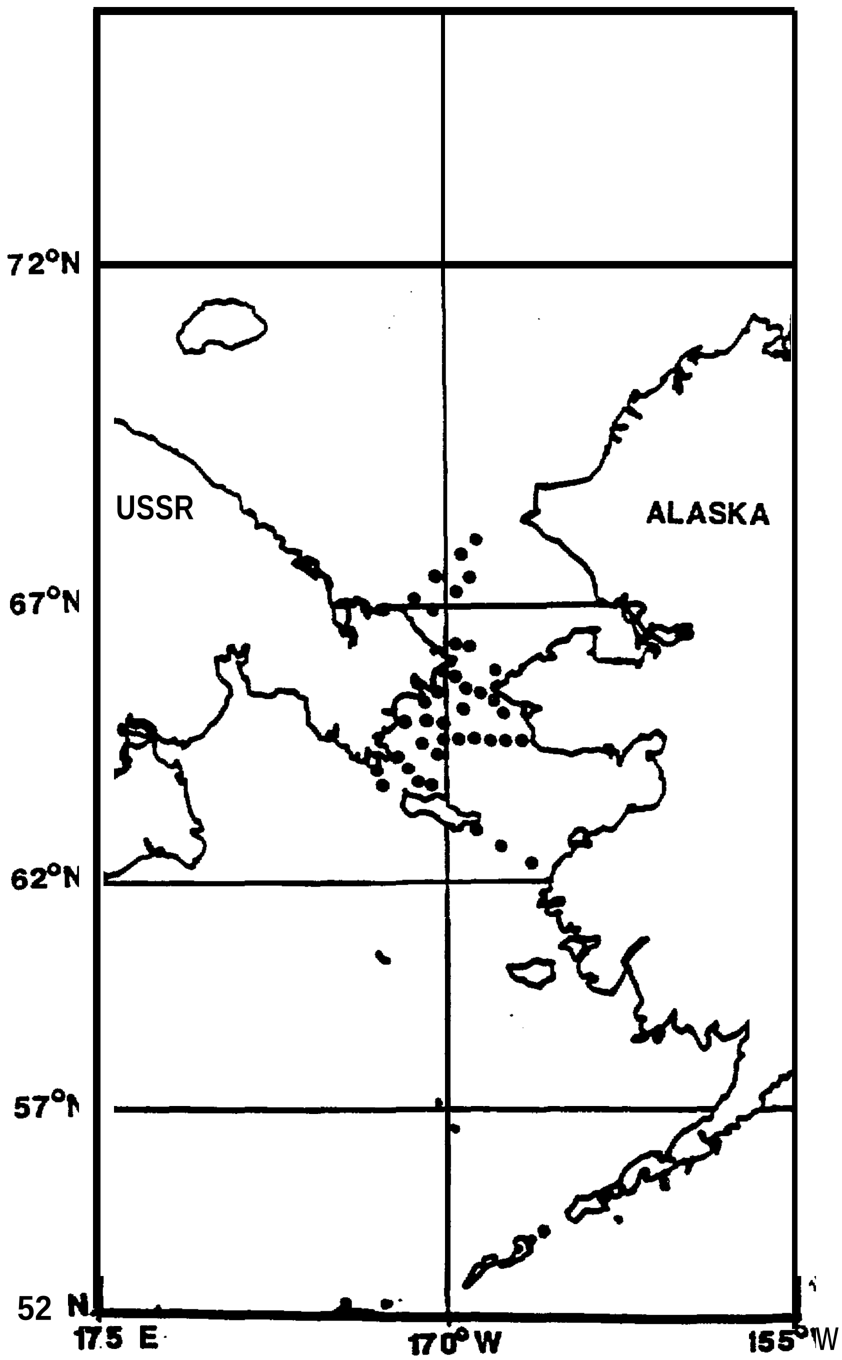

Figure 5. Stations sampled for zooplankton from the R/V THOMAS WASHINGTON, September - October 1988 (TW88).

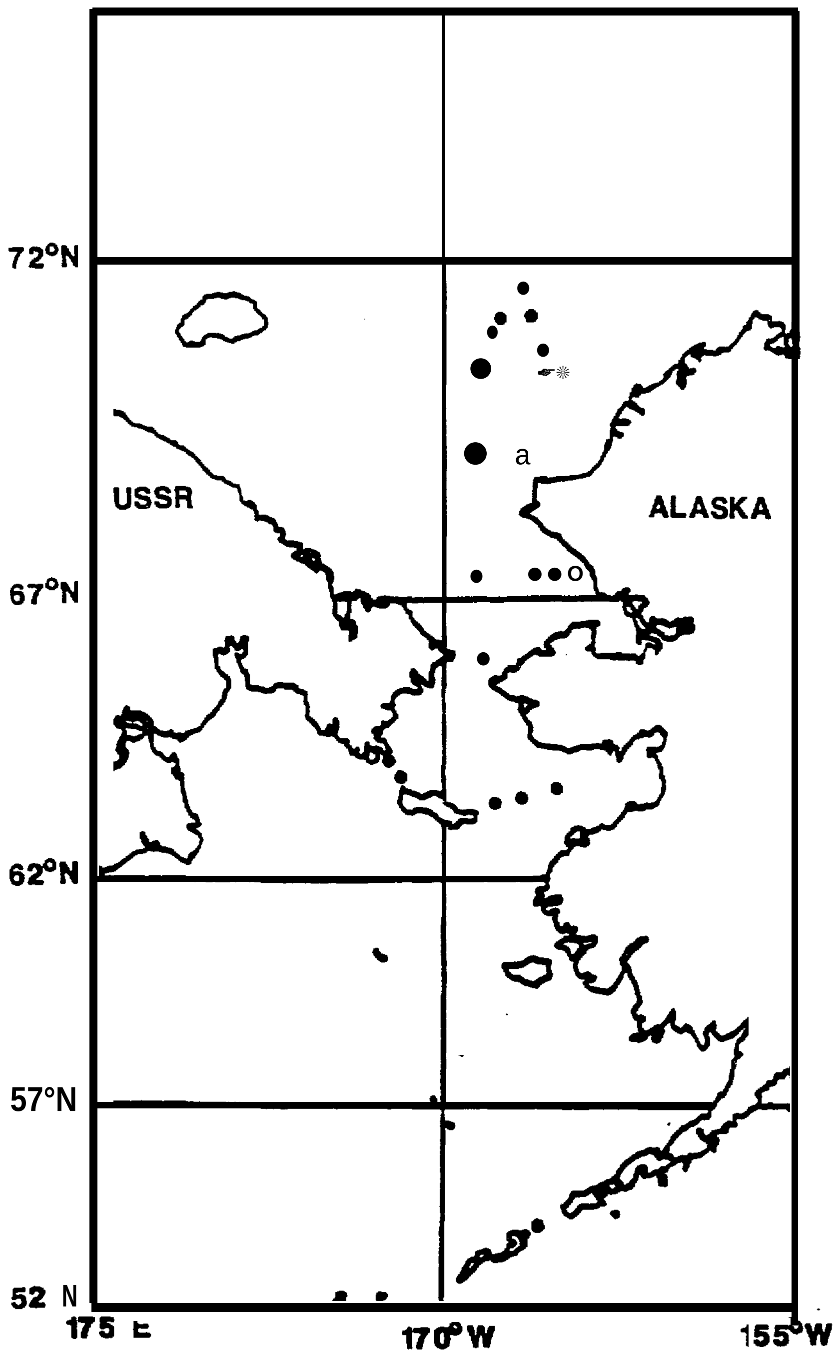

Figure 6. Stations sampled for zooplankton from the R/V SURVEYOR, October 1988 (SU88).

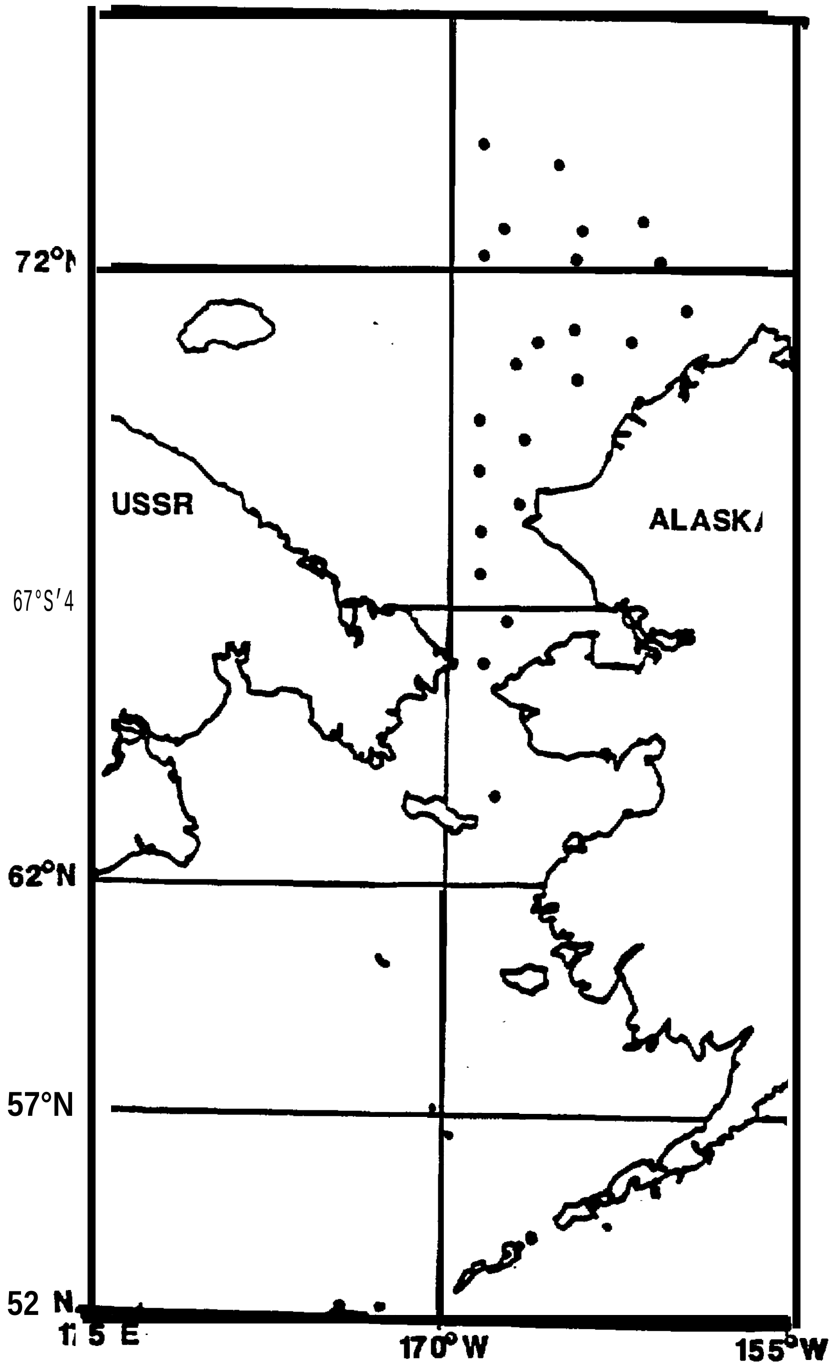

Figure 7. Stations sampled for zooplankton from the R/V SURVEYOR, October 1989 (SU89).

VIII. METHODS

Zooplankton Sampling - Samples of zooplankton were collected at the stations shown in Figure 1 - 7 with the use of bongo nets in open water or ring nets in areas of broken pack ice. Typically, oblique tows were conducted through the water column to within 5 - 10 m of the bottom. Multiple tows were taken until sufficient sample size was obtained to provide enough biomass to allow isotopic analysis on the major taxa present. Samples were sorted on board as soon as possible, to the species level if feasible, or at least to general taxon.

Sorted samples containing greater than 200 mg C wet weight were acidified with 10 percent HC1 to remove carbonates and dried to constant weight. A subsample of approximately 15 mg was then ground with copper oxide and placed in a 9 mm x 200 mm quartz tube. The tubes were loaded on a vacuum manifold and evacuated to <5 mTorr, then sealed with a torch for combustion. Samples were combusted at 870° for 2 hr and allowed to cool overnight. At this point the sample had been converted to carbon dioxide, nitrogen and copper sulfate. The tubes were opened onto the vacuum manifold and the nitrogen and carbon dioxide separated by cryogenic distillation. The purified gases were collected in short lengths of 6 mm glass tubing for later mass spectrometry.

Baleen Samples - Specimens of the longest baleen plates from the whales listed in Table 2 were collected by personnel of the North Slope Borough Department of Wildlife Management. Upon receipt, plates were cleaned of adhered gum tissue and then scrubbed with steel wool to remove surface films of algae and other foreign matter. A strip of adhesive tape marked off in centimeters was placed along the length and the baleen sampled at 2.5 cm intervals using a flexible shaft engraving tool. The fine powdered baleen was collected and stored in a vial until treated and combusted as described above.

Muscle and Fat Samples – The samples of frozen soft tissue were trimmed while frozen to remove possible surface contaminants and then a subsample of approximately five grams of muscle or fat was dried at 70° to constant weight. Muscle tissue was converted to a hard lump by drying, but the fatty tissues were rendered to a clear or yellowish oil. Subsamples of muscle were treated similarly to the baleen. The oil from fats was subsampled with a micropipette and approximately 15 mg placed onto a piece of precombusted glass fiber filter paper. This was then ground with copper oxide and treated as above.. No nitrogen samples were collected from the oil due to the extremely low N content.

Isotope Ratio Analysis - Mass spectrometry was performed using a VG Isogas mass spectrometer. Machine reproducibility was typically better than ±0.05 ppt on split samples and overall sample reproducibility was better than ±0.2 ppt on replicates carried through the entire process.

X. DATA MANAGEMENT

In-house Quality Assurance and Control -- sample processing and mass spectrometry results are incorporated into a rigorous in-house quality control and assurance program. Baleen is subsampled from plates collected and identified as to animal and date by personnel of the North Slope Borough Dept. of Wildlife Management. Baleen plates are engraved with an identifying number to preclude loss of attached identifiers during cleaning and subsampling. The subsamples are stored in labeled vials. Both baleen plates and vialed subsamples are available for resampling in case of handling mishaps. During collection of carbon dioxide and nitrogen from combusted samples, gas samples are split to provide exact replicates to test mass spectrometer replicability.

Laboratory standards consist of organic carbon standards provided by the National Bureau of Standards. We also maintain secondary working standards of tank gases and a bowhead whale baleen standard that has been calibrated in our laboratory and at the University of Texas and the Marine Biological Laboratory, Woods Hole, Massachusetts. Baleen standards are carried through the entire analytical procedure at regular intervals and whenever new reagents are used or any change in procedure occurs.

Internal consistency and replicability was tested by running two plates from the same whale (87B3-A,B). The isotope traces from these plates are shown below. The very close conformation of the two analyses is strong indication that the isotopic compositions of the baleen plates are identical at temporally equivalent locations along the longitudinal axes.

In-house Data Management -- Data are recorded in three forms. (1) Samples are identified in laboratory books and the isotope ratios recorded in hard copy. (2) The mass spectrometer computer prints out a machine record of the sample and the statistics of the analysis; and (3) all data are stored on computer files (Lotus 1-2-3) with periodic back-up.

Data Archiving Program -- No specific format has been established by the National Oceanographic Data Center for stable isotope ratio data. The Principal Investigator is consulting with NODC personnel to establish a suitable format.

XII PRELIMINARY RESULTS

Zooplankton Isotope Ratios -- Figure 8 and Table 1 show the $\delta^{13}C$ values for euphausiids and copepods collected from the Bering and Chukchi seas during 1987, 1988. and from the SURVERYOR cruise in 1989. Average $\delta^{13}C$ values were significantly depleted in 1988 and 1989 relative to 1987 for copepods but only the SU88 euphausiids were significantly more depleted than euphausiids collected in 1987. In all cases, euphausiids were enriched by approximately 1.0 - 1.5 ppt relative to copepods collected from the same station. This enrichment is similar to that described by Saupe et al. (1989) and the absolute values for both copepods and euphausiids match closely with the values listed for samples collected in June 1987 from the northern Bering Sea (Table 11.

Statistical Comparisons of ZooPlankton Data - The small trends shown in the $\delta^{13}C$ of zooplankton will be submitted to rigorous statistical tests to ascertain if the apparent intra- and interannual trends are significant. We will also compare rigorously the regional differences in isotope ratios by cruise to seek out any trends evident in the Bering - Chukchi zooplankton.

The strong advection of zooplankton northward through the Bering Strait is evident in that when data from all stations were statistically tested for regional differences, no significant differences were found for either copepods or euphausiids in either a north - south or east - west direction within the Bering and Chukchi seas. Again, this is similar to

Table 1. Averages, standard deviations, range and number of zooplankton $\delta^{13}C$ determinations for copepods, euphausiids and chaetognaths collected from the Bering and Chukchi seas, 1987 - 1989.

		Copepods	Euphausiids	Chaetognaths
T. G. Thompson 1987				
	mean	-21.22	-19.42	-20.04
	s.d.	0.63	0.67	0.23
	maximum	-19.92	-18.40	-19.70
	minimum	-22.42	-20.27	-20.24
	n	32	33	14
Surveyor 1987				
	mean	-21.66	-20.22	-20.58
	s.d.	1.29	0.83	0.42
	maximum	-19.74	-18.47	-20.10
	minimum	-24.42	-21.76	-21.43
	n	32	11	14
Ice Edge 1988				
	mean	-20.20	-20.08	-19.42
	s.d.	0.46	0.40	0.40
	maximum	-19.41	-19.58	-19.42
	minimum	-21.14	-20.79	-20.87
	n	13	8	16
Akademik Korolev 1988				
	mean	-22.18	-20.72	-21.24
	s.d.	0.98	1.11	0.94
	maximum	-20.54	-17.73	-19.92
	minimum	-25.25	-22.65	-23.99
	n	31	24	21
Thomas Washington 1988				
	mean	-21.83	-21.16	-21.13
	s.d.	1.23	0.97	1.28
	maximum	-19.58	-19.86	-18.65
	minimum	-24.12	-22.89	-23.94
	n	37	17	18
Surveyor 1988				
	mean	-23.46	-21.40	-20.77
	s.d.	0.56	0.74	0.69
	maximum	-22.36	-20.07	-19.68
	minimum	-24.58	-22.45	-22.04
	n	19	13	14
Surveyor 1989				
	mean	-22.40	-21.18	-20.59
	s.d.	1.08	0.76	0.68
	maximum	-18.90	-19.83	-19.60
	minimum	-24.72	-22.62	-21.86
	n	39	28	21

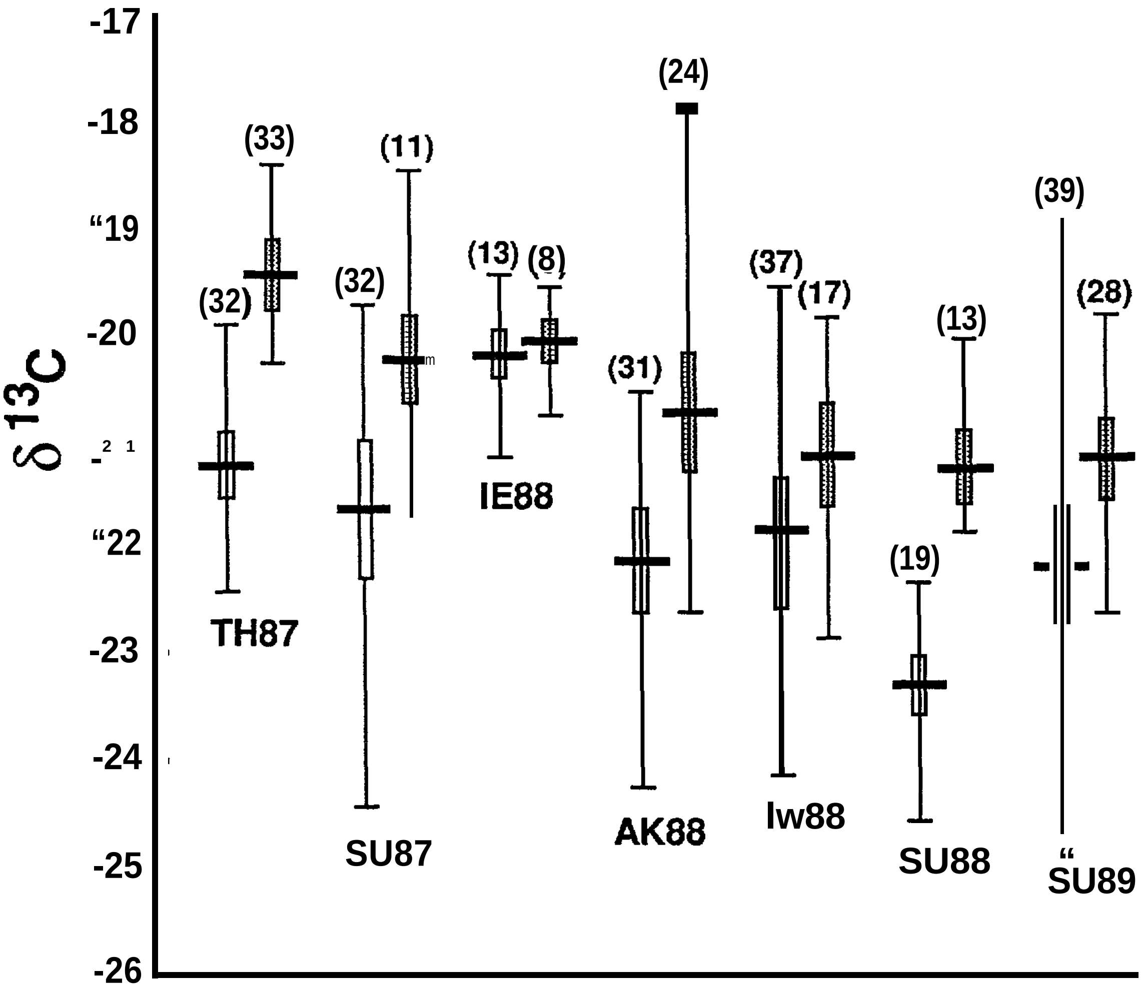

Figure 8. Average (bar), range (vertical line) and standard deviation (box) of carbon isotope ratios of euphausiids (shaded boxes) and copepods (open boxes) from cruises in the Bering and Chukchi seas, 1987-1989.

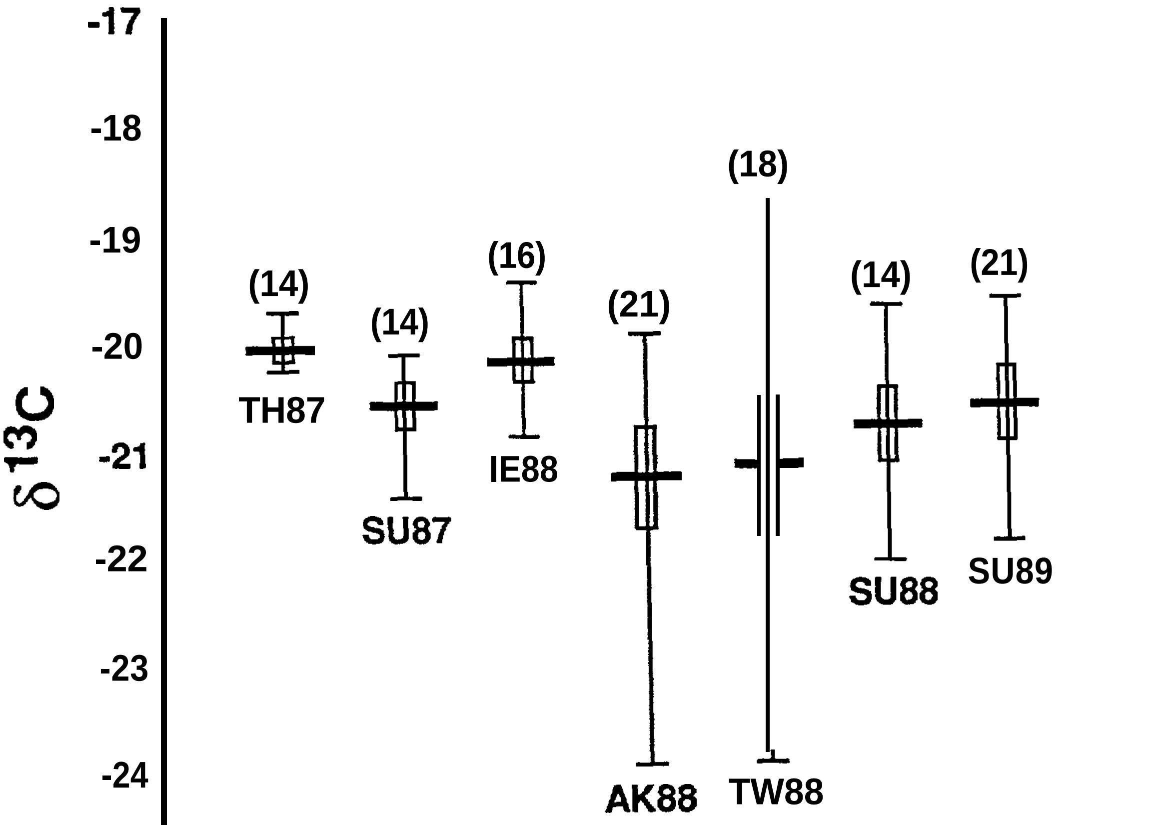

Figure 9. Average (bar), range (vertical line) and standard deviation (box) of chaetognaths collected from cruises in the Bering and Chukchi seas, 1987-1989.

the findings of Saupe et al. (1989) who noted increasing depletions in $\delta^{13}C$ primarily across the Beaufort Sea. We will be conducting further tests on data from individual cruises and on seasonal effects.

Chaetognaths are the principal predator of copepods and were abundant in almost all samples collected. Their carbon isotope ratios reflected the $\delta^{13}C$ of copepods and were approximately 1 o/.. more enriched as anticipated from their trophic position (Figure 9). The averages from all cruises fall between $\delta^{13}C$ = -20.0 to -21.1°/00. Saupe et al. (1989) reported an average value of $\delta^{13}C$ = -20.90/.. for samples collected in June 1987 from the northern Bering Sea. As with the copepods, the chaetognaths collected in late summer and fall showed a slightly depleted average $\delta^{13}C$ relative to 1987 samples from the same time period. The $\delta^{13}C$ of copepods, euphausiids and chaetognaths collected from the SURVEYOR in 1989 (SU89) were in turn slightly enriched compared to the previous year. We cannot tell from the data whether the changes in the average $\delta^{13}C$ of a taxa are a seasonal response or an interannual variation due to changes in the physiochemical regimes of the water masses. These variations in the average $\delta^{13}C$ of zooplankton appear to be reflected in the baleen of the whales feeding upon them.

Bowhead Whale Baleen Isotope Ratios - Average $\delta^{13}C$ values for muscle, fat, and baleen are listed in Table 2 and individual $\delta^{13}C$ values for the baleen plates from the whales analyzed to date are shown in Figure 10. The traces encompass ages ranging from a near-term fetus (87B5F) to adults in excess of 23 years of age. All whales showed evidence of isotopic changes of the same magnitudes and periods as reported by Schell et al. (1987). Yearling whales all had distinctive natal notches near the tips of the baleen plates and several of these animals had been identified as "ingutuks" by Inupiat whalers, supporting the conclusion of Nerini et al. (1984), that this morphological variant is a recently weaned yearling.

By measuring the incremental changes in baleen growth rates between isotopic cycles along the plates, ages were determined for the subadults using the technique described in Schell et al. (1989b). The findings, reported in Table 3, have been incorporated into the body length versus age and the baleen length versus age curves previously reported by Schell et al. (1989b). Beyond age four, the growth in body length in subadults is nearly linear with age with a slope of 0.44 m/year. Projecting this growth

Table 2. Bowhead whales analyzed for δ13C of baleen and/or body tissues for this study and previously by Schell et al. (1 987). Dashes denote no sample; "inc" denotes incomplete analysis at the time of this reporting.

Whale Name	Collected dd/mm/yy	Sex	Body Length (m)	Avg. $\delta^{13}C$ Baleen (‰)	Baleen Length (cm)	# of Samples	Visceral Fat $\delta^{13}C$ (‰)	Blubber $\delta^{13}C$ (‰)	Muscle $\delta^{13}C$ (‰)	Other $\delta^{13}C$ (‰)
66B1	10/05/66	M	9.7	-18.68	175	63	—	—	—	—
86B1	27104166	M	8.2	-18.79	118	43		—	—	—
86B2	27104188	M	8.7	-18.66	52	28		-25.80	-20.1	—
86B3	30104188	F	8.9	-19.09	160	52	—	—	-20.7 (2)	—
86B4	01105186	M	8.9	-16.77	130	52	—	—	-19.6	—
86B5	04105186	M	8.1	-18.24	65	53	-24.4	—	-19.1	—
8606	05105186	F	12.3	-19.46	230	81	-25.7	—	-19.7	—
86B7	06105186	M	10.7	-19.07	201	49	-24.7	—	-20.0 (3)	—
86KK1	17/09/86	F	7.6	-19.02	130	49	-27.6 (2)	-26.02 (3)	-21.4	—
86KK2	17109186	F	17.1	-17.81	380	165	-25.0	-25.35	-19.2	—
86KK3	26109186	M	10.4	-19.28	185	50	-27.0	-26.50	-21.4	—
86WW1	05105186	M	15.9	-17.66	269	133	-25.0	—	-18.8	—
66WW2	10/05/86	F	17.7	-17.79	310	200	-25.8	-25.77	-19.4	—
87B1	01/05/88	M	9.3	inc	168	38		—		—
87B2	02105187	F	8.9	-18.50	150	60		—		—
87B3-A	04105187	M	11.0	-18.97	195	78	—	—	—	—
87B3-B	04105187	M	11.0	-19.03	195	79	—	—	—	—
87B4	20105187	F	16.8	-18.45	317	118		—	—	—
87B5	15/06/87	F	15.7	-18.45	300	120		—	—	—
87B5F	15106187	fetus	4.0	-18.20	15	14	—	-19.47 (8)	-18.94	—
87B6	22110187	F	15.7	-17.98	315	105	-23.56	-24.68 (24)	-19.20 (2)	-15.75 (2) (tendon)
8707	29110187	M	8.5	-18.79	85	34	-25.50	-26.11 (14)	-20.83	—
87G2	24104187	F	16.8	-16.17	345	138	—	—	—	—
87H4	28105187	M	7.8	-18.42	68	27	—	—	—	—
87N1	05105187	F	15.2	-16.72	330	132		-25.63 (71)	-20.85 (2)	—
87WW2	08105187	M	13.5	-18.89	215	86		—	—	—
87WW3	15/05/87	F	8.2	inc	208	72	—	—	—	—
88B1	24104188	F	6.9	-18.57	98	39	-24.99 (2)	—	-20.16	—
88B10	17/09/88	M	15.1	inc	328	132		—		—
88B11	17/09/88	F	15.6	inc	340	137	—	—	—	—
88B2	25104188	M	8.6			—	-24.45	-25.63 (11)	-19.43	—
88B3	25104188	F	7.8				-25.28	—	-19.24	—
88B4	25104188	F	9.0	-18.56	130	52	—	—	-19.28 (2)	-17.34 (tendon)
88B6	02105188	F	8.3				-25.26 (C.V.F.)*	—	-19.94 (2)	-19.49 (tendon)
88B6	02/05/88	F	8.3			—	-25.69 (R. V.F.)**	—	—	—
88B6	02105188	F	8.3	—			—	—	—	-19.62 (liver)
6807	05105186	F	8.2	-16.60	78	31	-25.71 (R.V.F.)**	—	-20.30	-21.11 (liver)
88B8	06105186	F	7.5	-18.61	130	52	-21.44 (C.V.F.)*	—	-19.52	-16.66 (tendon)
8808	06105188	F	7.5	—	—		-25.59 (R.V.F.)**	—	—	-20.22 (liver)
88B9	151091e8	M	14.6	inc	253			—	—	—
88G1	16/04/88	F	15.7	-18.44	295			—	—	
88G2	25104188	F	15.3	-18.41	275		—	—	-19.06	
88KK1	24109188	F	14.9	inc	297	102		—	—	—
88WW1	25104168	F	7.9	-18.31	75	30		—	—	
88WW2	26104188	M	9.1	-18.91	98	39		—	—	
88WW3	06105188	F	13.4	-19.68	207	83	—	—	—	

● Cardiac Viscerel Fat
● *Renal Visceral Fat

Table 3. Bowhead whale (B. *mysticetus*) growth rate data from $\delta^{13}C$ analyzed baleen plates. "Estimated age" represents actual age of the animal assuming birth occurred in spring. "Baleen Growth Increments" are the number of $\delta^{13}C$ cycles in the given length range, progressing from the tip of the plate toward the jaw. Asterisks indicate missing increments lost through erosion from tip.

Whale[a]	(sex)	(season taken)	Body Length (m)	Baleen Length (m)	No. of Baleen Growth Increments (cm/yr) >45	35-45	27.5-35	<27.5	Estimated Age (years)
† 87B5F	(Fetus)	Spring	4.0	0.15					
86B2	Female	Spring	8.7	0.65	1				1
† 87WW3	Female	Spring	8.2	0.60	1				1
† 87H4	Female	Spring	7.8	0.65	1				1
† 88B7	Female	Spring	8.2	0.77	1				1
† 88WW1	Female	Spring	8.9	0.77	1				1
† 87B7	Male	Fall	8.5	0.78	1				1.5
86B5	Female	Spring	8.1	0.95	1	1			2
† 88B1	Female	Spring	8.9	0.97	1	1			2
† 88WW2	Male	Spring	9.1	0.95	1	1			2
† 88B4	Female	Spring	9.0	1.30	1	1	1		3
86KK1	Female	Fall	7.6	1.45	2	1			3.5
86B1	Male	Spring	8.2	1.35	1	1	1	1	4
† 88B8	Female	Spring	7.5	1.30	*	*	1	4	7
86B4	Male	Spring	8.9	1.50	*	1	1	4	7
86B3	Female	Spring	8.9	1.70	*	1	1	4	7
† 87B1	Male	Spring	9.3	1.62	(incomplete analysis)				
86KK3	Male	Fall	10.4	1.85	*	1	1	4	7.5
† 87B2	Female	Spring	8.9	1.72	*	1	1	5	8
66B	Male	Spring	9.7	1.75	*	1	1	6	9
86B7	Male	Spring	10.7	1.90	*	*	1	8	11
† 87B3	Male	Spring	11.0	1.95	*	*	*	10	≥13
† 87WW2	Male	Spring	13.5	2.15	*	*	*	11	≥14
86B6	Female	Spring	12.3	2.40	*	*	*	12	≥15
† 87N1	Female	Fall	15.2	3.25	*	*	*	14	>17
† 87B5	Female	Spring	15.7	3.00	*	*	*	16	>19
† 87B4	Female	Spring	16.8	2.75	*	*	*	17	>20
86WW1	Male	Spring	15.9	3.15	*	*	*	17	>20
† 87B6	Female	Spring	15.7	3.15	*	*	*	18	>21
† 87G2	Female	Spring	16.8	3.45	*	*	*	19	>22
86KK2	Female	Fall	17.1	3.80	*	*	*	20	>23
86WW2	Female	Spring	17.7	3.75	*	*	*	20	>23

a. Indicates year, location and sequential number of kill. B = Barrow; G = Gambell; H = Point Hope; N = Nuiqsut; WW = Wainwright; KK = Kaktovik.

† Whales analyzed for this study. Other data from Schell et al. (1987).

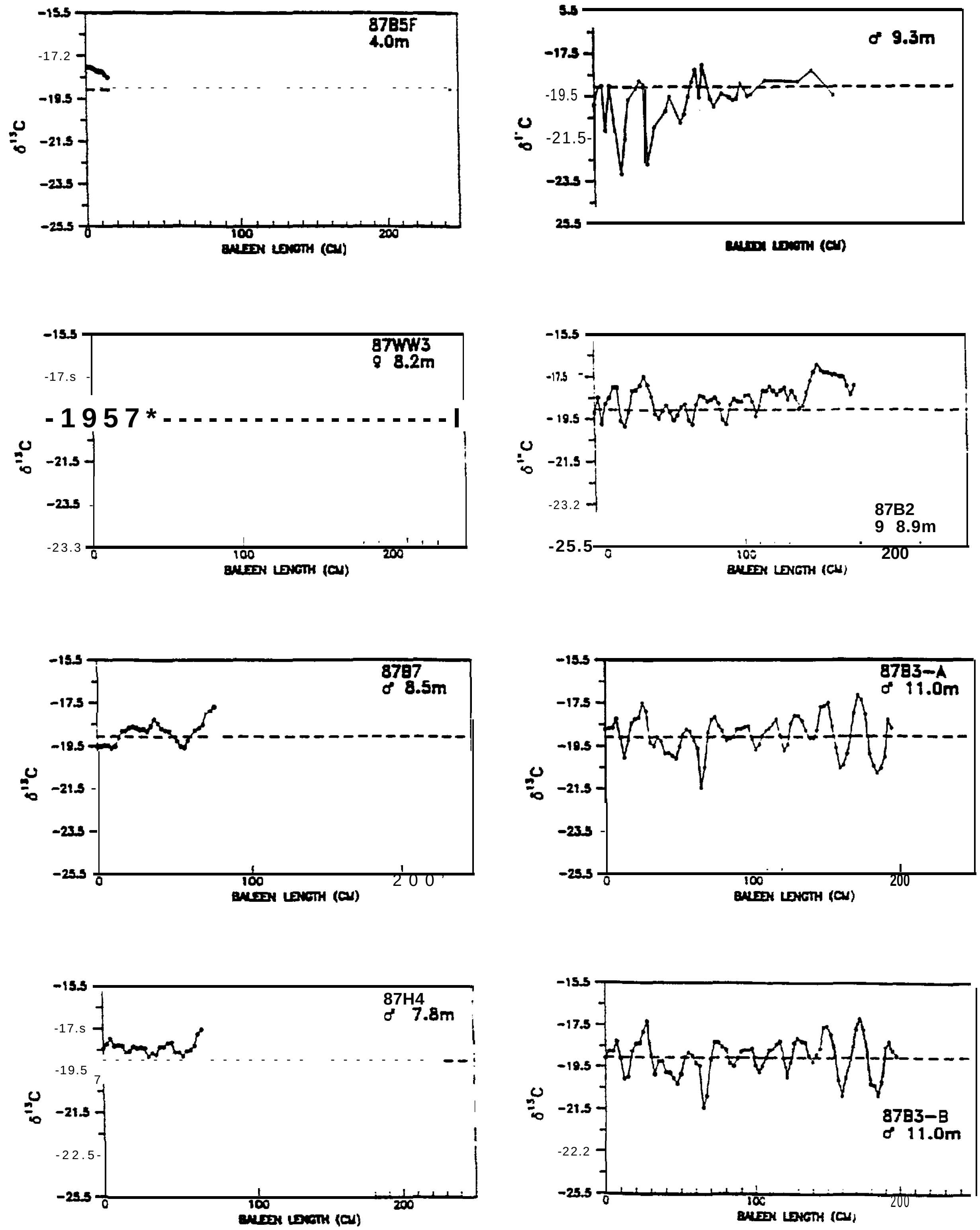

Figure 10. Sex, body length, and $\delta^{13}C$ values along the length of baleen plates of bowhead whales, *Balaena mysticetus*, analyzed in this study. Base of each plate (newest baleen) is at left in each trace. Alphanumeric identification of each whale indicates year, location , and sequence of take (B = Barrow, G = Gambell, H = Point Hope, KK = Kaktovik, N = Nuiqsut, WW = Wainwright. Whale 87B3-A,B plates taken from the left and the right side of the mouth.

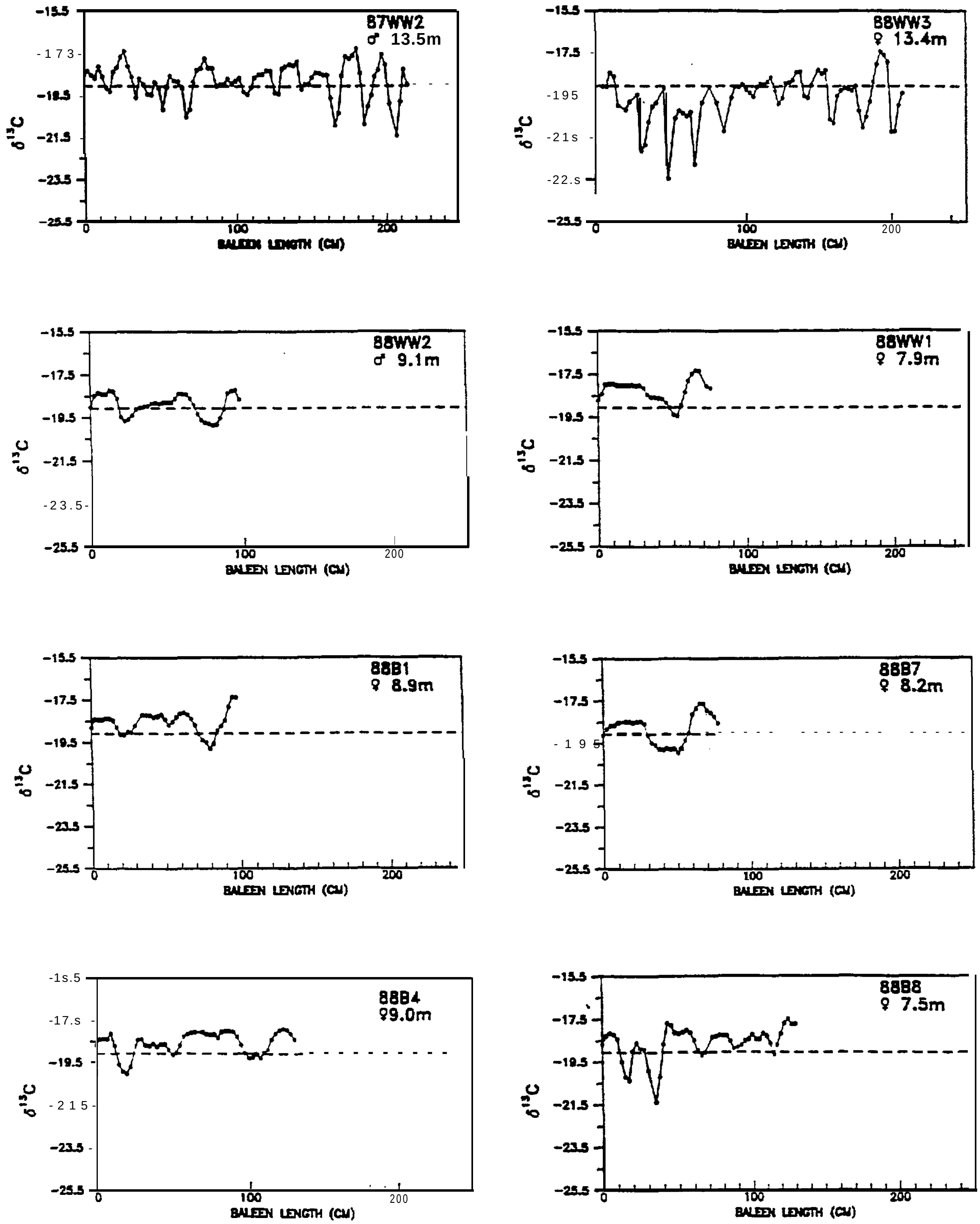

Figure 10 (Continued).

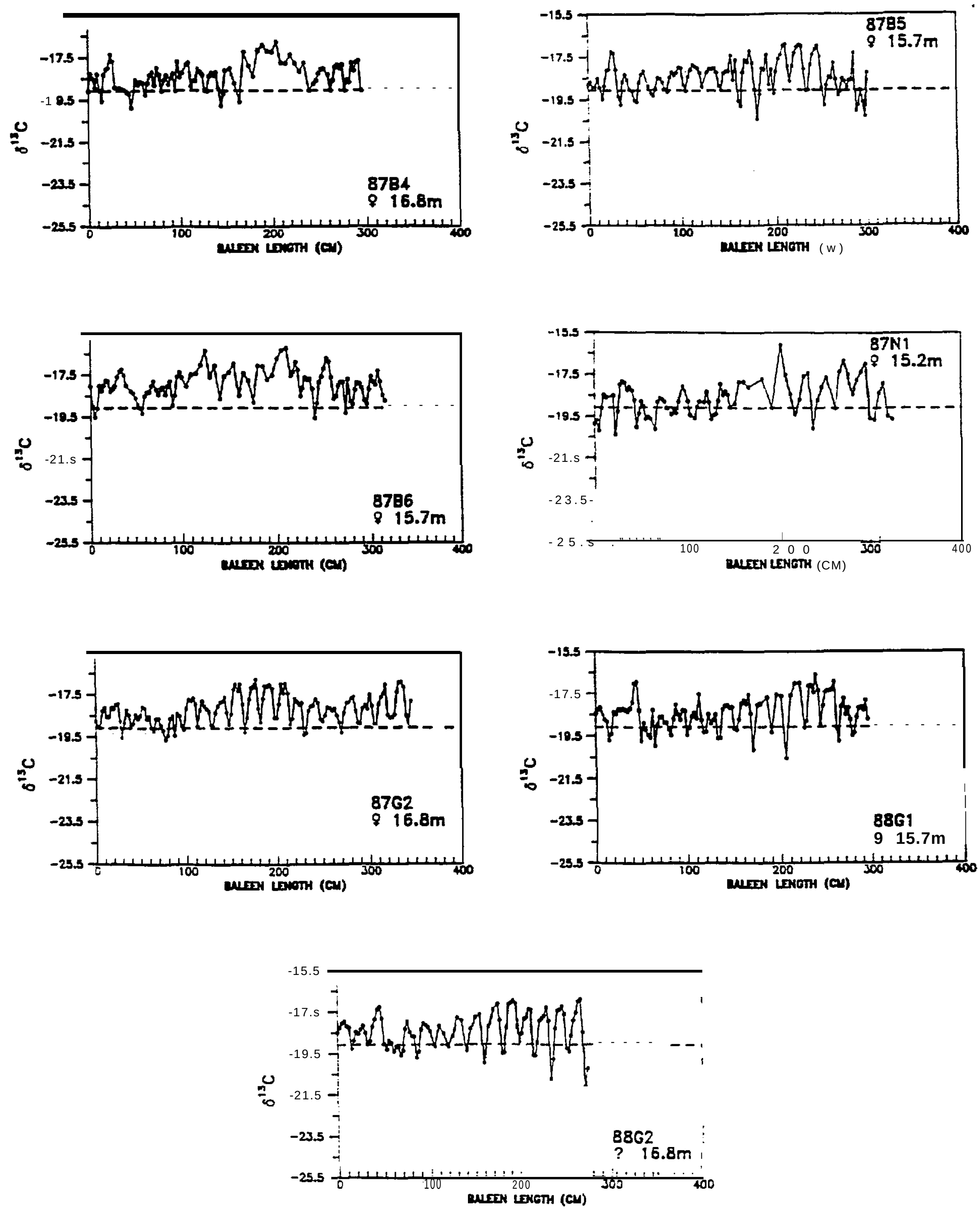

Figure 10 (Continued).

rate to the assumed age of sexual maturity at 13 - 14 m in length yields ages between 16 - 19 years (Figure 11). These estimates are slightly less than the previous estimates of 18 - 20 years (Schell et al., 1989b).

Baleen length remains the best indicator of age in young whales. The data acquired in this study have been plotted with the data from Schell et al. (1989b) and the modified curve is shown in Figure 12. The best-fit power curve for baleen length versus age is now:

$$Y = 2.52\ X^{1.95}$$

where Y = age in years and X = baleen length in meters. The points for whales 87B3, 87WW2, and 86B6 are "best estimates" and the uncertainty is greater than that for younger whales. The incremental changes in baleen growth rates are indiscernible in these whales due to wear off the distal end of the plates. The age estimates assume a loss of three years baleen growth from the tip of the plate.

Following weaning, there is a period of very little linear growth which persists for several years. Whale 88B8 was estimated at 7 years of age and had a body length of 7.5 m. This was shorter than any of the yearlings analyzed to date although the baleen, at 1.3 m in length, was almost double the length of the yearlings (see Table 2). Observers of the whale noted that the animal was very thin and had a relatively thin layer of blubber. Whale 87B2, with an estimated age of 8 years, was 8.9 m in length, well within the same length range as yearlings. The baleen in this whale was 1.72 m in length. Figure 11 illustrates this diapause in growth very clearly.

Environmental control of carbon isotope ratios -- Closer examination of the isotope records in the baleen from large whales reveals that on a multi-year basis, the winter $\delta^{13}C$ values undergo year-to-year changes and often show trends of either increasing or decreasing ^{13}C content over periods up to 5 or 6 years. Comparison of the isotope records between large whales also shows that the trends usually, but not always correlate, indicating that the source of the variability is probably in the food consumed from the winter environment. We do not know the source of these longer term changes. One possibility is that the relative abundances of euphausiids versus copepods changes over multi-year periods and this change is relected in the feeding of the whales and the composition of the baleen.

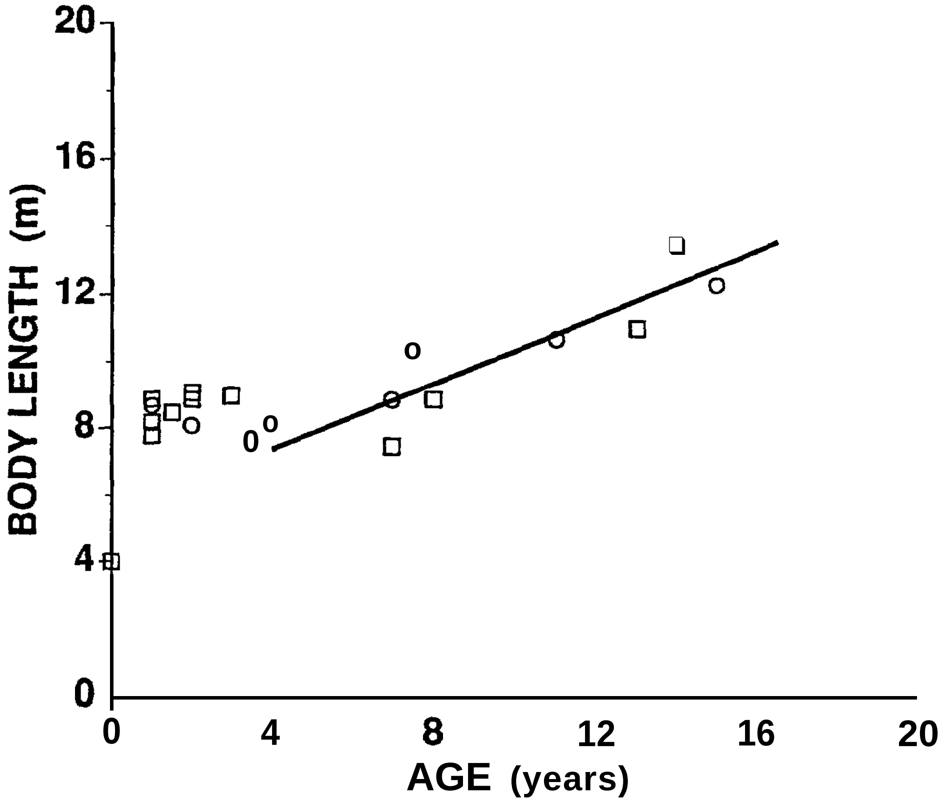

Figure 11. Body length and age of subadult bowhead whales analyzed for this study (boxes) and from Schell et al. (1989) (circles). The regression line is drawn from age four; slope = 0.44 m/year.

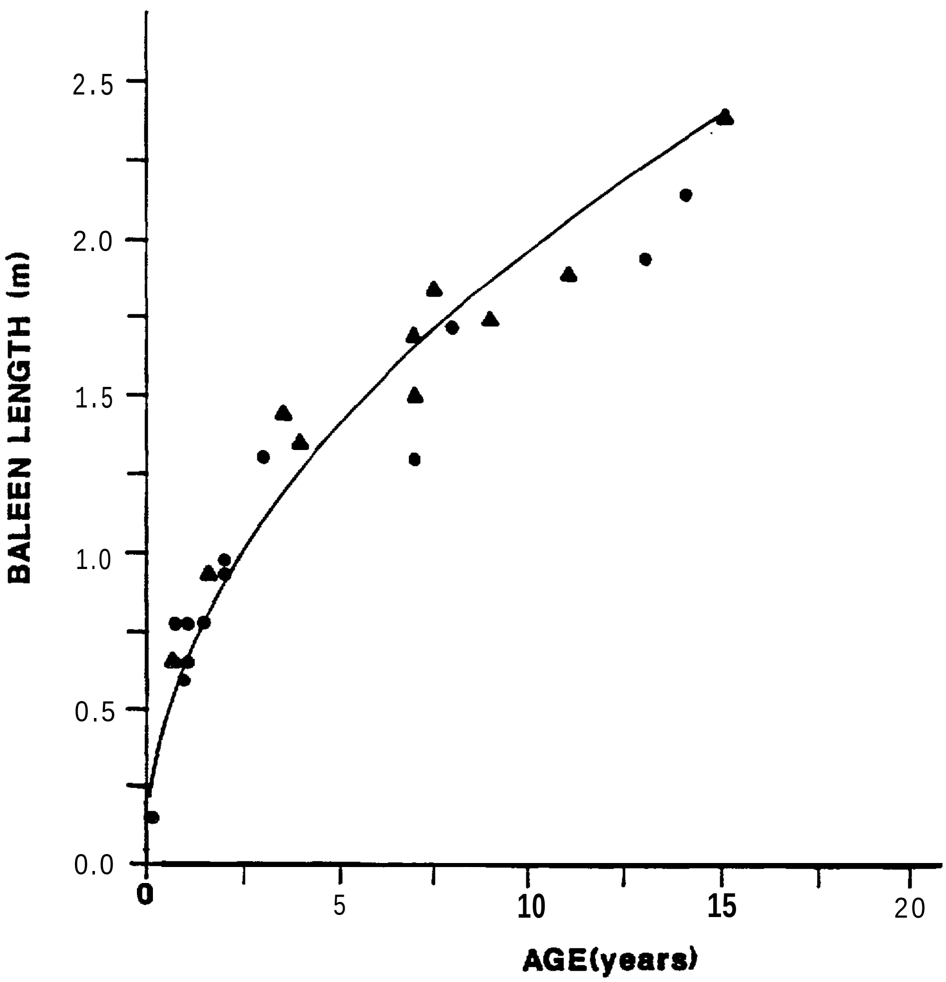

Figure 12. Baleen length and age of subadult bowhead whales analyzed in this study (circles) and by Schell et al. (1989) (triangles). Best-fit power curve is shown.

Euphausiids have a $\delta^{13}C$ approximately 1.5 ‰ enriched relative to copepods. -Alternatively, the changes may relate to the physiochemical characteristics of the water masses in which the phytoplankton and zooplankton live. Rau et al. (1989) has proposed that the latitudinal gradients in phytoplankton $\delta^{13}C$ arise from the size of the free carbon dioxide pool in seawater and this in turn responds to temperature. At low temperature, the free carbon dioxide concentrations in seawater are largest and thus phytoplankton fixing carbon from this pool may discriminate in favor of the lighter isotope. He uses this mechanism to explain the latitudinal gradients evident in zooplankton in Antarctic waters.

Our data tend to contradict the hypothesis of Rau et al. (1989). We find that in reviewing the intra-seasonal trends of $\delta^{13}C$ for copepods and euphausiids, they are most enriched at the start of the season when water temperatures are coldest and carbon dioxide concentrations would be expected to be higher (see Figure 8). The cruises for 1988 span the period June through October. We feel, therefore, that until the floristics of the phytoplankton successions have been studied as well as the phsyical characteristics of the water masses wherein the primary production occurs, the mechanisms for the observed changes in $\delta^{13}C$ remain uncertain.

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